NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3435

A STATISTICAL STUDY OF WING LIFT AT GROUND CONTACT FOR FOUR TRANSPORT AIRPLANES

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SUMMARY

A statistical study of the values of wing-lift factor at the instant of ground contact is presented for four transport airplanes. The basic data were obtained from acceleration measurements on VGH records of 2,049 landings of four commercial-airline transport airplanes during normal operations. Frequency-distribution curves and probability curves were fitted to the samples of data obtained from each of the transport airplanes.

The results indicate that the mean value of the wing-lift factor K_L at ground contact is very nearly 1, the value in the steady-state airborne condition. The deviation of K_L from the mean value is such that in 95 percent of the landings for all airplanes considered the lift factor does not differ from 1 by more than ±0.1. The probability of obtaining a value of K_L as low as 0.8 or as high as 1.2 is approximately 1 in 10,000.

INTRODUCTION

Very little data on the value of wing-lift force at ground contact have been available which can be used to establish a criterion for the design of land-based airplanes. As a result, present design requirements are not consistent regarding this criterion. For example, U. S. Air Force requirements assume the lift force at ground contact to be equal to the weight of the airplane (ref. 1), whereas the U. S. Navy (ref. 2) and the Civil Aeronautics Board (ref. 3) specify that the value of wing lift used for design purposes shall not exceed two-thirds the weight of the airplane.

The use of the NACA VGH recorder in connection with statistical studies of gust loads has provided a large number of records of airplane center-of-gravity accelerations which may be used to evaluate the wing lift at ground contact. This paper presents data obtained from VGH records for a total of 2,049 landings of the following four commercial transport airplanes in routine airline operations: the Martin 2-0-2, the Convair 240, the Boeing 377, and the Douglas DC-6. The data are summarized in the form of observed-frequency and cumulative-frequency distributions of wing-lift factor (ratio of wing-lift force to the weight of the airplane). In order to smooth out the irregularities in the data and to obtain some degree of extrapolation, frequency-distribution curves and corresponding probability curves were fitted to the observed distributions by standard statistical methods.

SYMBOLS

g	acceleration due to gravity
K_L	wing-lift factor, ratio of lift force to airplane weight
ΔK_L	class interval, equal to 0.05
f_o	observed frequency in class interval
f_t	calculated frequency
N	total observed frequency
$\bar{K}_L$	mean value of K_L
σ	standard deviation
α_3	coefficient of skewness
α_4	coefficient of kurtosis

SOURCE OF DATA

The NACA VGH recorder (ref. 4) was developed to measure time histories of airplane center-of-gravity acceleration, airspeed, and altitude for long periods of time. In normal use the VGH recorder continuously records these quantities from take-off through landing. A magnified portion of that part of a typical record which embraces the landing operation is shown in figure 1. Ground contact is determined from the acceleration trace by the abrupt change in frequency of the acceleration at the instant of touchdown. Since the rate of change of wing lift just prior to the instant of ground contact is low compared with the natural frequency of the wing in bending, dynamic effects are negligible and the airplane center-of-gravity acceleration in g units at the instant of ground contact is a direct measure of the wing-lift factor K_L.

The range of a typical VGH accelerometer is from -2g to 4g which corresponds to a full-scale deflection on the record of about $1\frac{3}{4}$ inches. The static accuracy of the acceleration measurement is within 1 percent of full scale and the record-reading error is considered to be within ±0.03g.

FREQUENCY DISTRIBUTIONS

Values of wing-lift factor K_L were obtained from 1,171 landings of the Martin 2-0-2, 437 landings of the Convair 240, 253 landings of the Boeing 377, and 188 landings of the Douglas DC-6. The data are summarized in table I in the form of frequency distributions of K_L. Although the class interval $\Delta K_L = 0.05$ used for these distributions is comparatively large, the accuracy of the readings was not considered sufficient to warrant the use of smaller intervals.

The distributions of K_L are plotted in figure 2 as histograms showing the relative frequency f_o/N in each class interval and the relative frequency per unit of class interval or density $f_o/\Delta K_L N$, where f_o is the number of observed landings falling in a given class interval and N is the total number of landings.

In order to smooth out the irregularities in the data and to provide some basis for extrapolation of the data, frequency-distribution functions f_t and resulting probability curves were fitted to the observed data by the method of moments as given in reference 5 (ch. IV). For this purpose the following statistical parameters were determined from the calculated moments for each of the observed distributions of K_L: the mean value $\bar{K}_L$, the standard deviation σ, the coefficient of skewness α_3, and the coefficient of kurtosis α_4. These parameters define the principal characteristics of the frequency distribution. The mean value defines the center of gravity of the distribution; the standard deviation defines the spread or variability from the mean; the coefficient of skewness defines the degree of asymmetry; and the coefficient of kurtosis defines the peakedness of the distribution. The values of these parameters obtained for each of the observed distributions are given in table I.

Examination of the values of the statistical parameters α_3 and α_4 and the application of statistical tests of normality (ref. 6, ch. VI) indicate that, for three of the four distributions of K_L, the values did not depart significantly from what would be expected for normal distributions; namely, $\alpha_3 = 0$ and $\alpha_4 = 3$. For the distribution for the Convair 240, however, the amount of skewness was found to be significantly greater than would be expected if the sample were from a normal universe. On the basis of the foregoing considerations, normal probability distributions were fitted to the data for the Martin 2-0-2, Boeing 377, and Douglas DC-6 airplanes. In view of the amount of skewness in the distribution for the Convair 240, a distribution function which would account for skewness was fitted. The Pearson system of generalized frequency-distribution curves was chosen and, on the basis of criteria given in reference 7, the Pearson type IV curve was fitted to the distribution for the Convair 240. For comparison, the normal curve was also fitted to the data for the Convair 240. These distribution curves are shown in figure 2. In order to permit a ready comparison of the variations in the distributions of the various samples of data, the fitted curves for each of the distributions are shown in figure 3.

The observed and fitted distributions for all samples of data were integrated from both ends to determine the probability that K_L will be greater than or less than a given value. These results are shown in figure 4. A comparison of the fitted probability curves is shown in figure 5.

DISCUSSION

The results shown in table I indicate that for all the samples of data the values of wing-lift factor at ground contact varied within the range from 0.8 to 1.2. The distributions of K_L had a mean value very close to 1 and a standard deviation of only about 0.04. The data for the Convair 240 and Boeing 377 airplanes indicated the greatest variability with a standard deviation of 0.045, whereas the data for the Douglas DC-6 airplane appeared to have the least variability with a standard deviation of 0.035. In general, in 95 percent of the landings for all airplanes ($\pm 2\sigma$ from the mean), K_L did not differ from 1 by more than ± 0.1. In view of the fact that the variability of the measured data includes the effects of instrument and reading errors, the actual spread of the lift factor from the mean should be somewhat less than is indicated.

The frequency-distribution curves and probability curves fitted to the observed data (figs. 2 and 4, respectively) indicate that, for three of the four samples of data, the normal curve provides a reasonable representation of the observed data, whereas the data for the Convair 240 are better represented by the Pearson type IV skewed-distribution curve.

The probability that K_L will be less than a specific value is of primary importance in determining the lower limit of lift factor at ground contact for design purposes. This lower limit is dependent upon the distribution of K_L and the number of landings expected for a given airplane during its useful lifetime. For example, if 10,000 landings is the expected number of landings for any transport airplane, these results indicate that the value of the lift factor at ground contact would not be less than 0.8 as shown by the summary plot in figure 5 at the probability level of 10^{-4}. For a particular airplane, however, the lower limit of K_L may be somewhat higher than 0.8 as shown by the curve fitted to the data for the Douglas DC-6.

The probability that the lift factor will be greater than a specific value of K_L is of less importance from the standpoint of critical loads on the landing gear but it may be important with regard to the acceleration during impact. In this respect, the skewed distribution from the Convair 240 results in somewhat higher values of K_L in comparison with the symmetrical distributions from the other samples of data.

The minor differences indicated between the distributions for these airplanes could be due to such factors as runway-approach terrain, pilot technique, airplane stability characteristics, and surface weather conditions. However, further analysis of the effect of such factors on the value of wing lift at ground contact is beyond the scope of this investigation.

CONCLUDING REMARKS

The results of a statistical study of wing lift at ground contact for four airline transport airplanes show that the value of the wing-lift factor K_L at ground contact varied from about 0.8 to 1.2, that the mean value was approximately equal to the steady-state airborne value $K_L = 1.0$, and that there were some minor differences indicated in the shape of the distributions of K_L. For each sample of data, the standard deviation of K_L was approximately 0.04, and in 95 percent of the landings for all airplanes considered the values of lift factor did not differ from 1 by more than ±0.1. The probability of obtaining a value of K_L as low as 0.8 or as high as 1.2 was approximately 1 in 10,000.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 24, 1955.

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TABLE I

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

K_L	Observed frequency f_o for airplane -			
	Martin 2-0-2	Convair 240	Boeing 377	Douglas DC-6
0.85 to 0.90	13	3	2	------
0.90 to 0.95	136	31	19	11
0.95 to 1.00	458	188	89	70
1.00 to 1.05	463	150	106	95
1.05 to 1.10	93	56	32	12
1.10 to 1.15	7	8	5	------
1.15 to 1.20	1	1	-----	------
Total, N	1,171	437	253	188
$\bar{K}_L$	0.997	1.004	1.007	1.004
σ	0.043	0.045	0.045	0.035
α_3	-0.039	0.356	0.039	-0.220
α_4	3.219	3.371	3.190	2.844

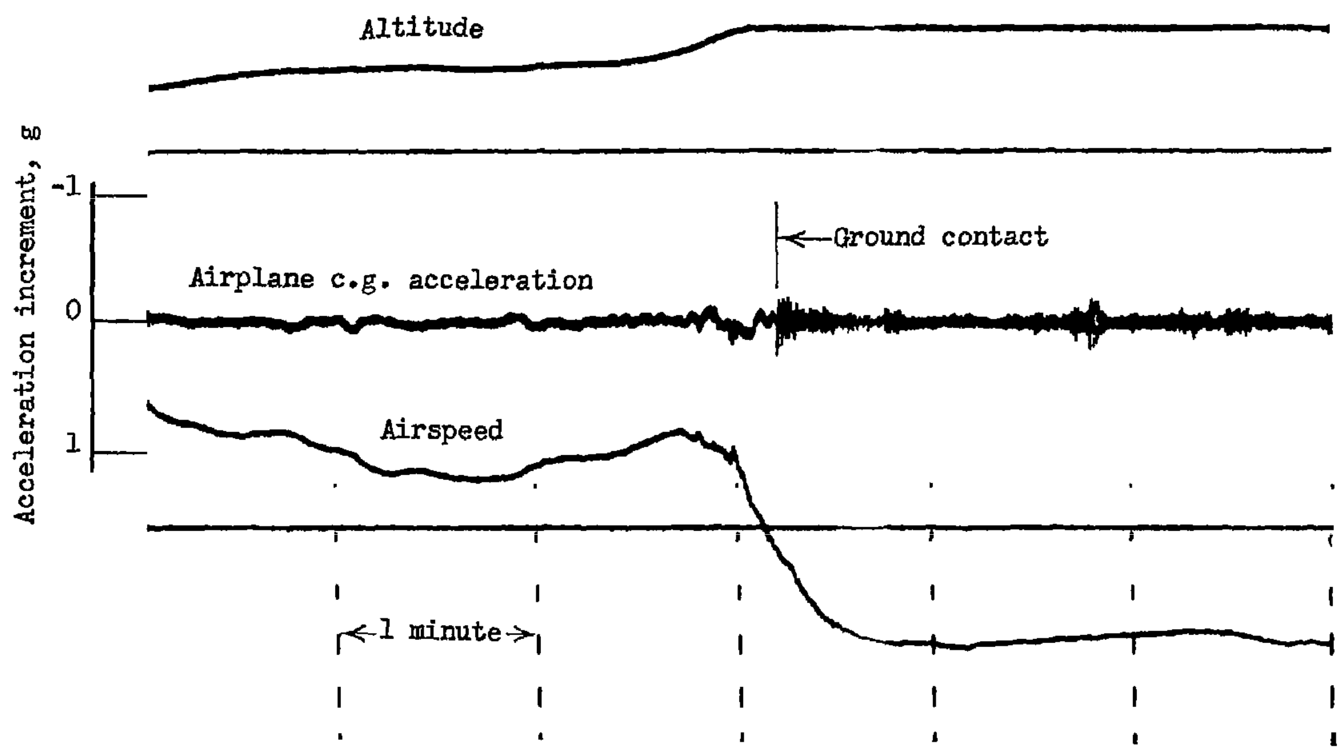
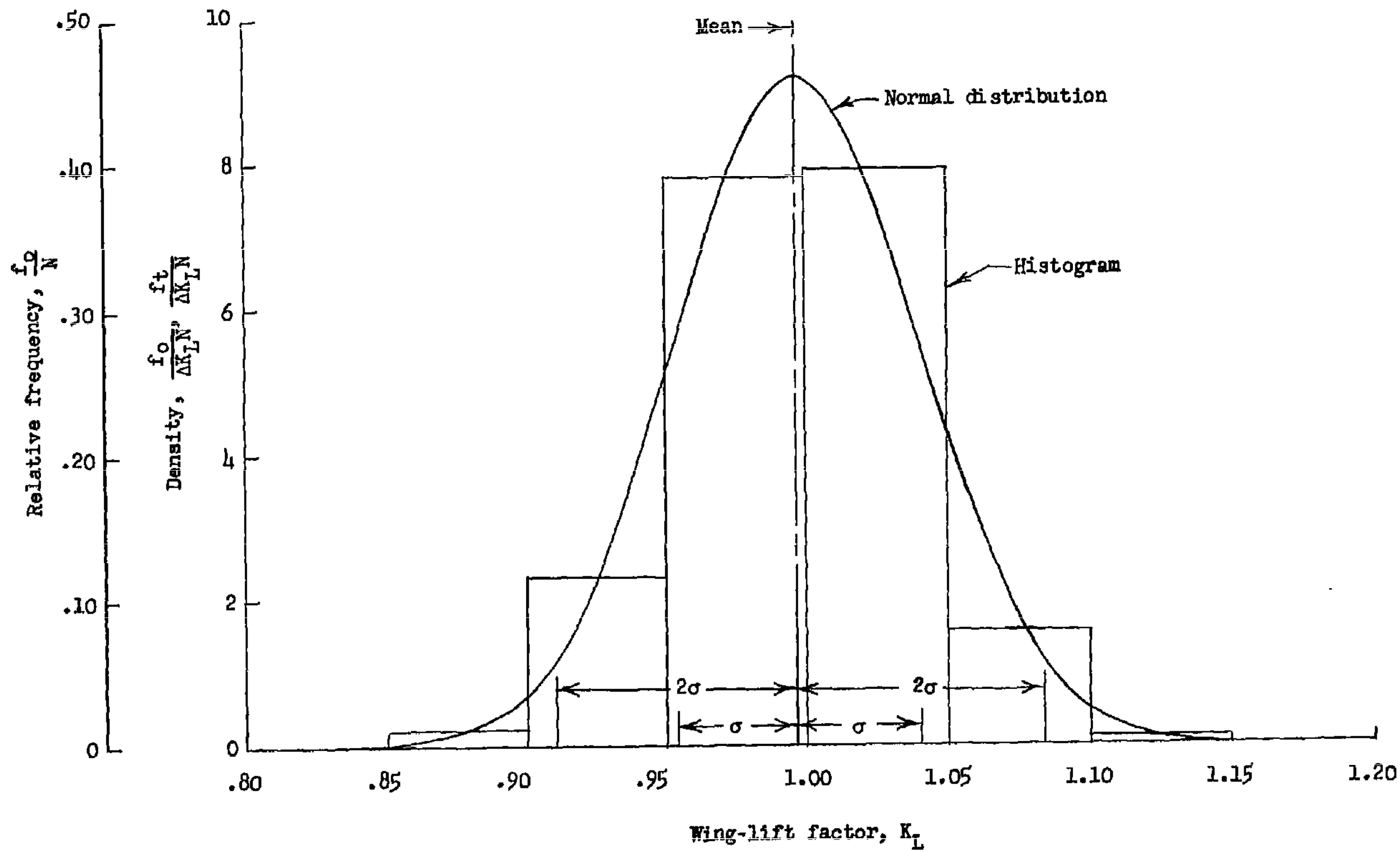
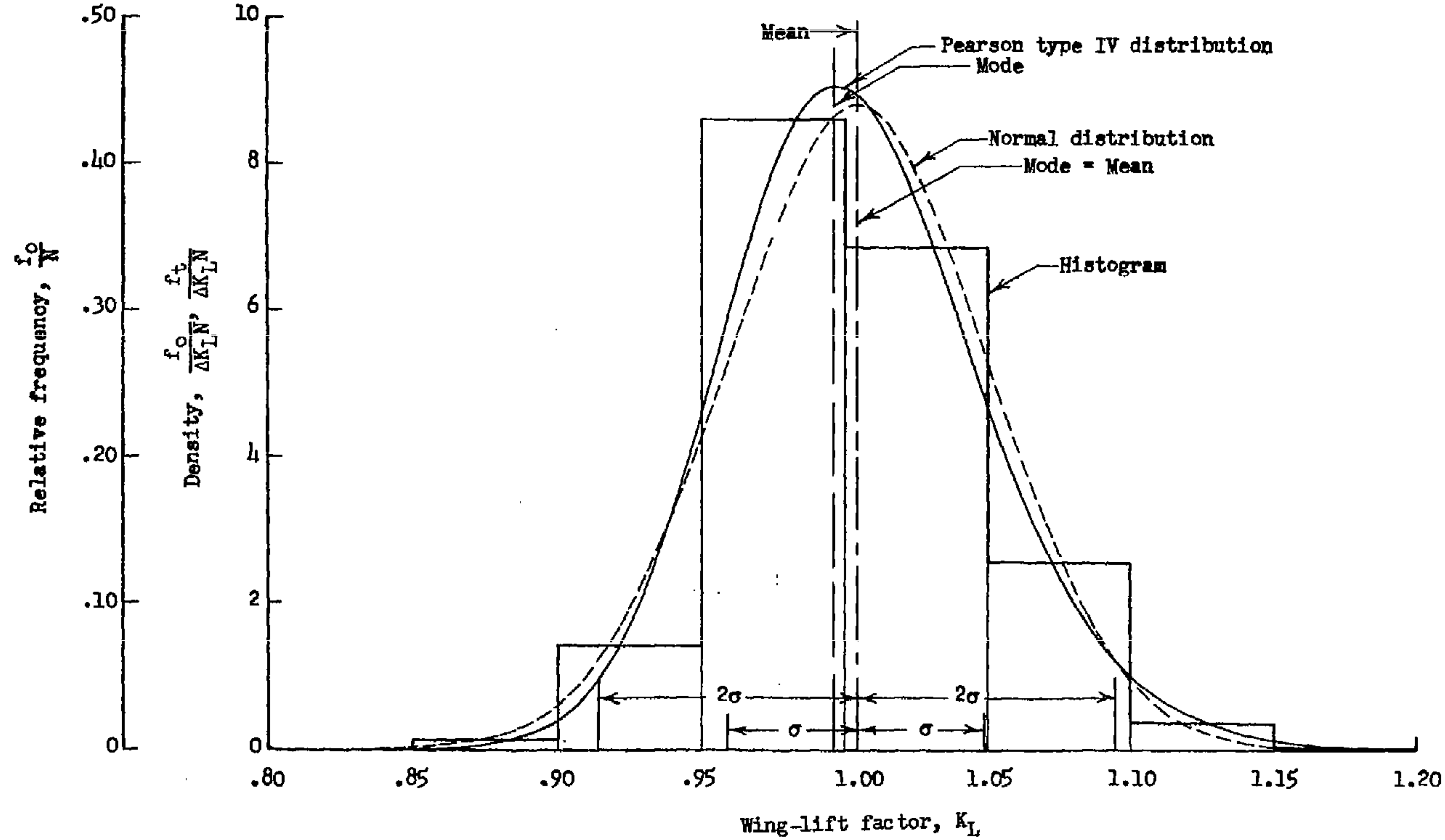


Figure 1.- Enlarged portion of typical VGH record at landing interval.



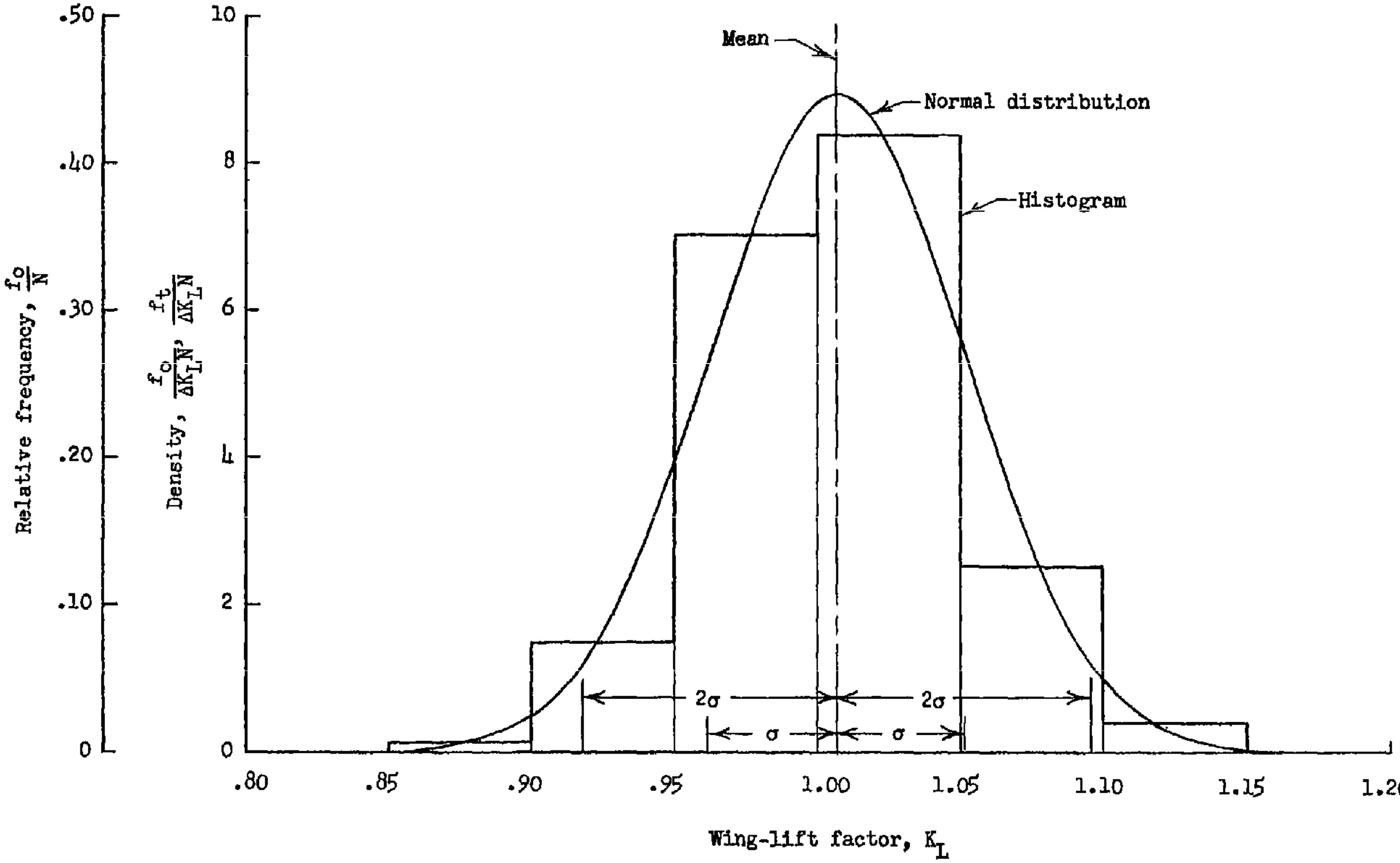
(a) Martin 2-0-2 airplane. $N = 1{,}171$; $\bar{K}_L = 0.997$; $\sigma = 0.043$.

Figure 2.- Frequency distribution of wing-lift factor at instant of ground contact.



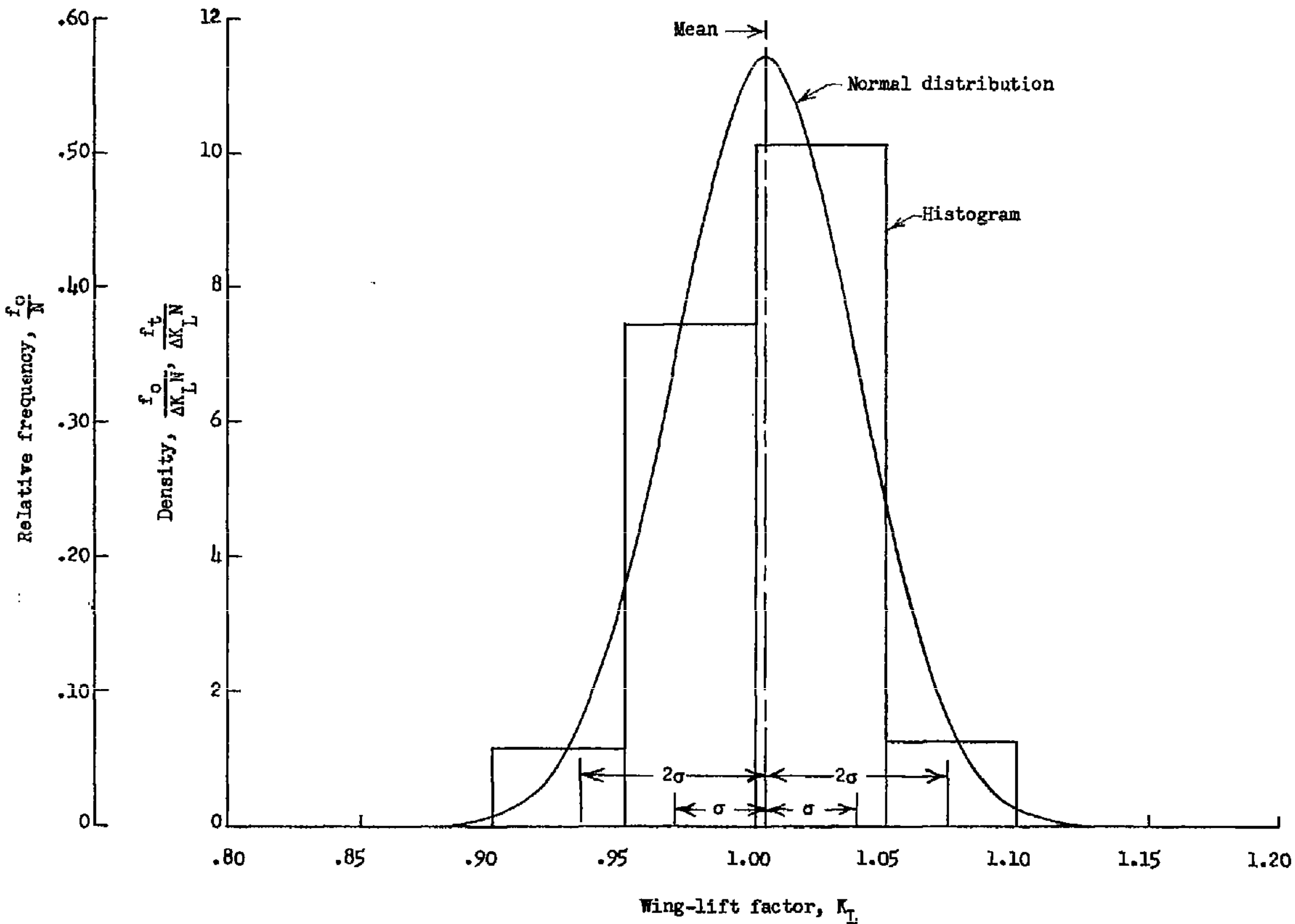
(b) Convair 240 airplane. $N = 437$; $\bar{K}_L = 1.004$; $\sigma = 0.045$.

Figure 2.- Continued.



(c) Boeing 377 airplane. $N = 253$; $\bar{K}_L = 1.007$; $\sigma = 0.045$.

Figure 2.- Continued.



(d) Douglas DC-6 airplane. $N = 188$; $\bar{K}_L = 1.004$; $\sigma = 0.035$.

Figure 2.- Concluded.

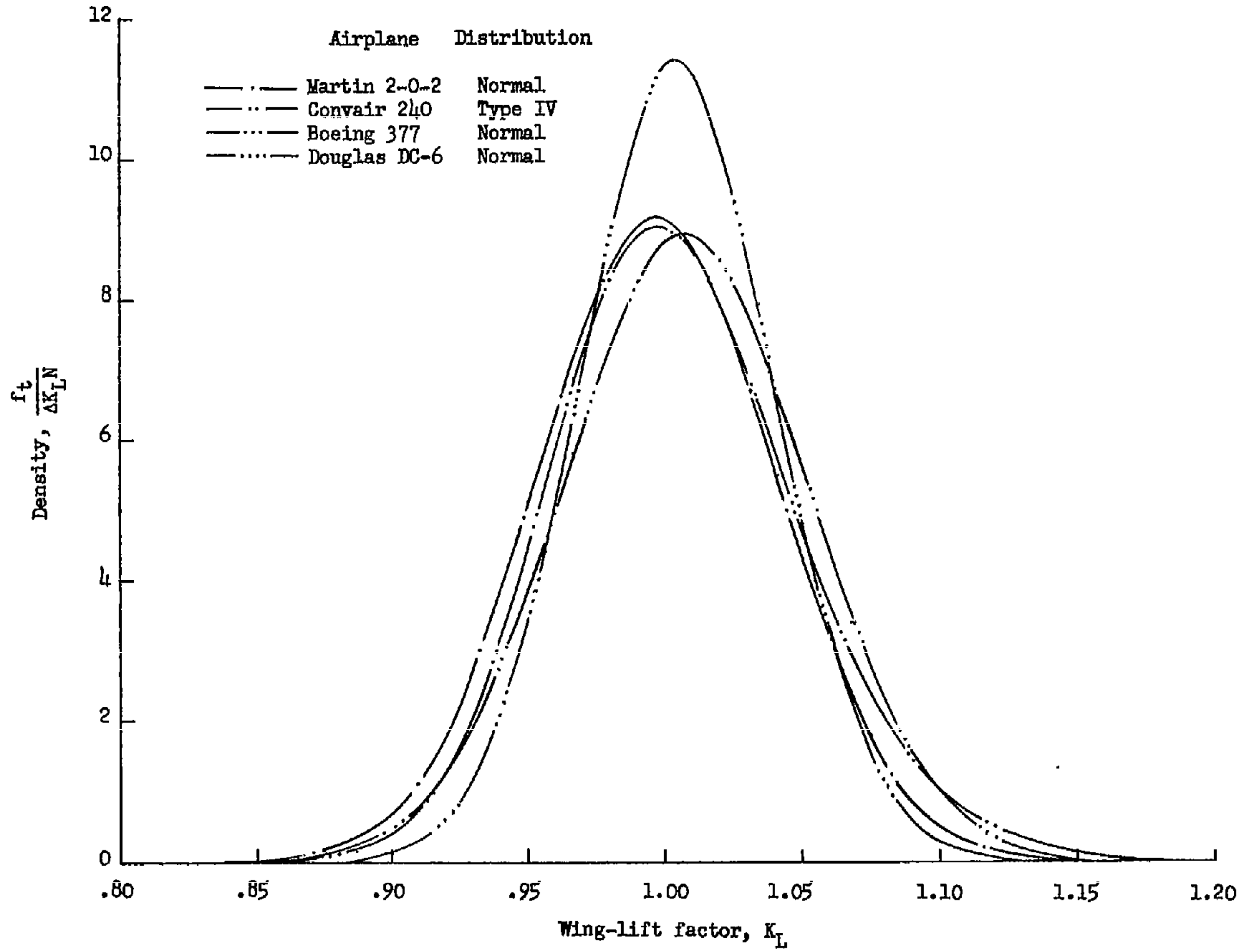
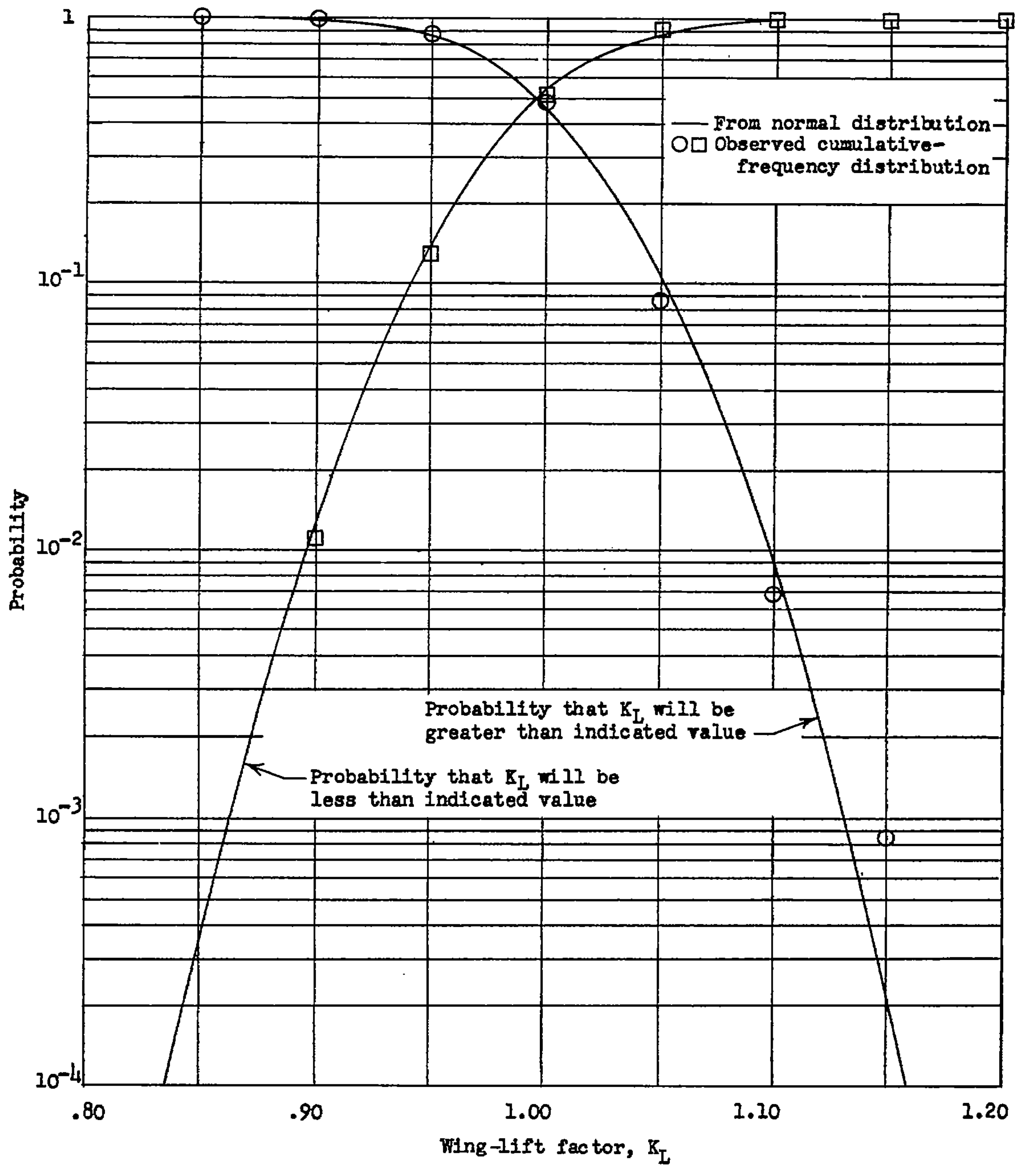
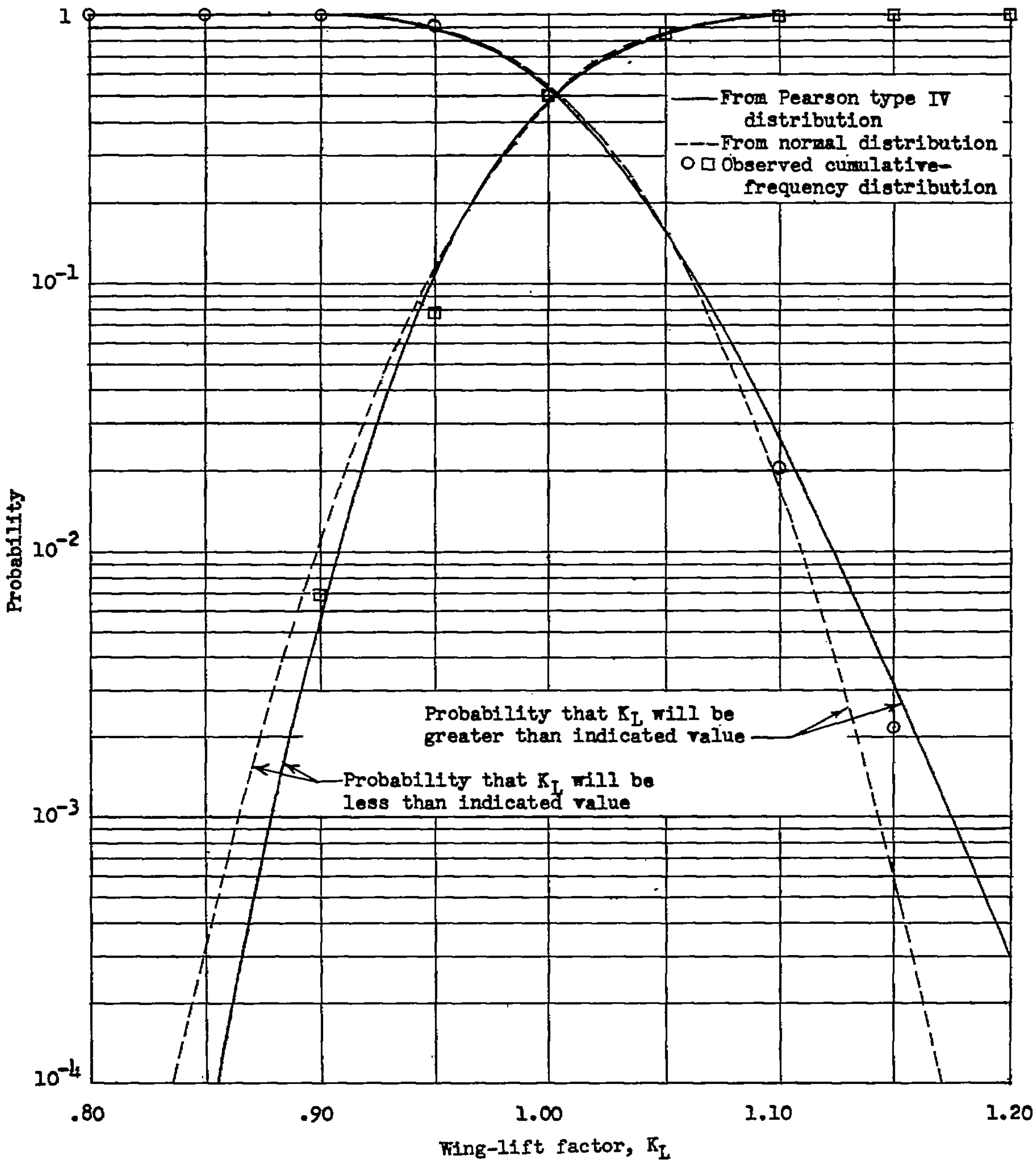


Figure 3.- Comparison of fitted frequency-distribution curves of wing-lift factor at instant of ground contact for all samples of data.



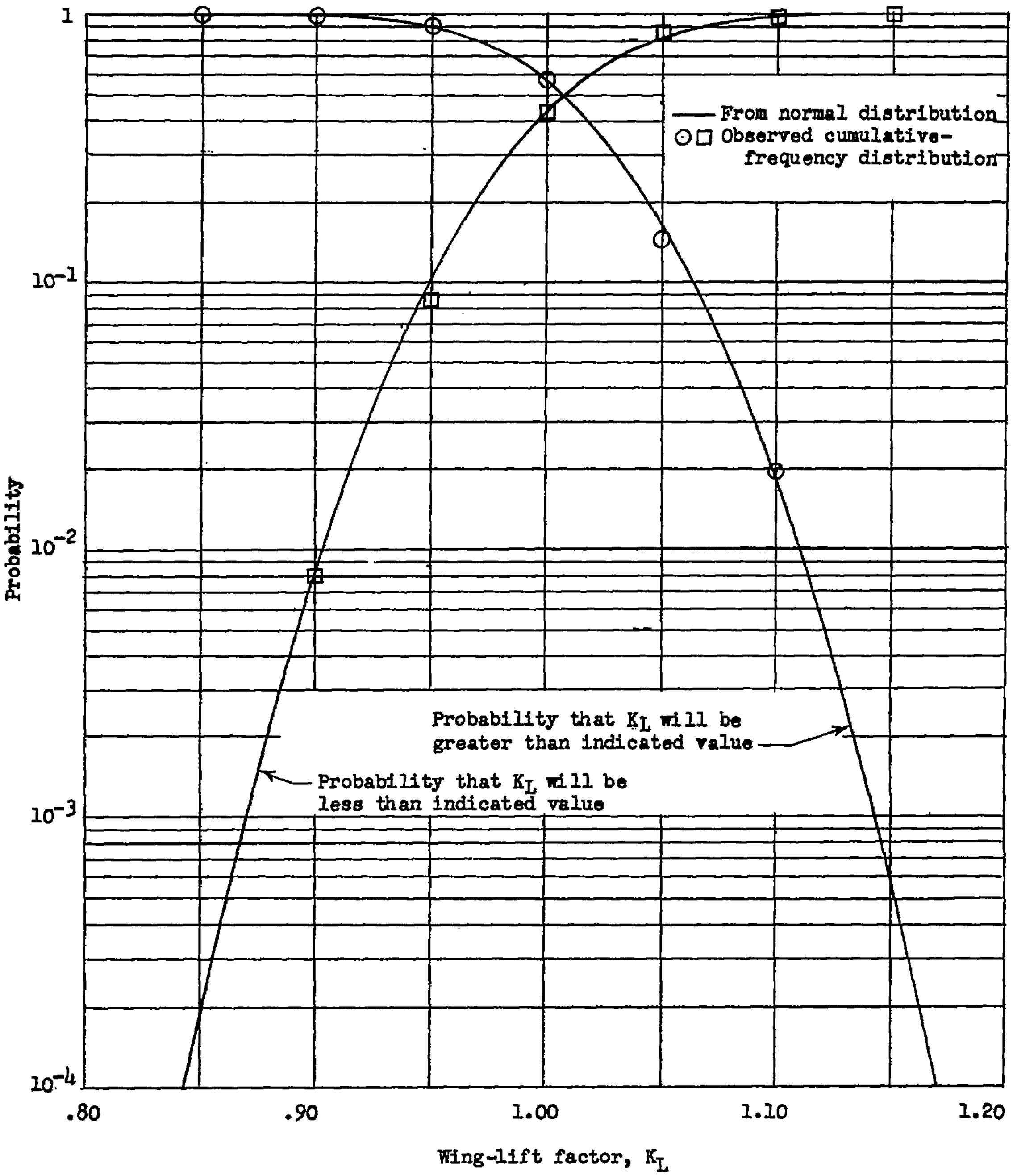
(a) Martin 2-0-2 airplane.

Figure 4.- Probability that wing-lift factor at instant of ground contact will be greater than or less than the indicated value.



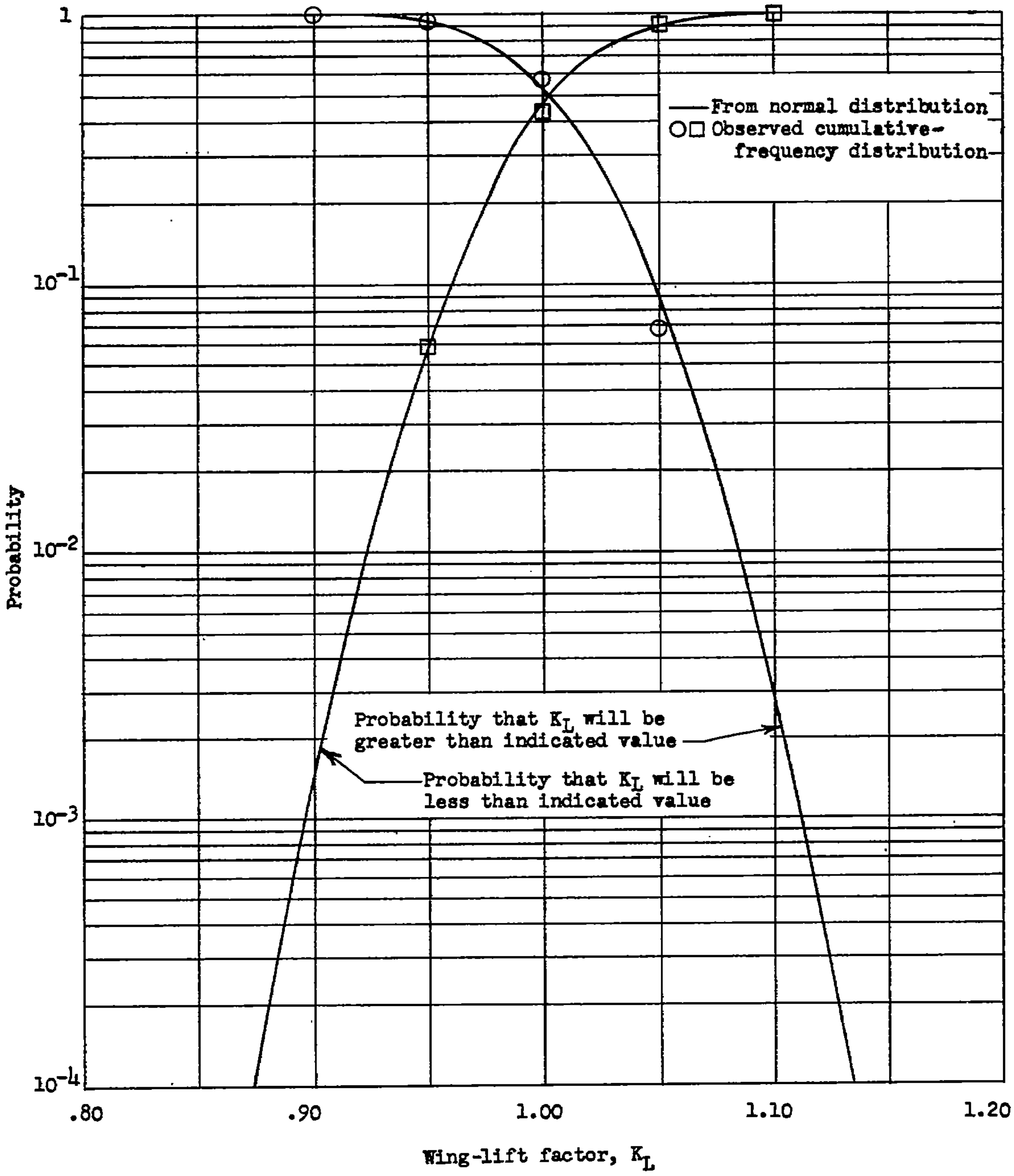
(b) Convair 240 airplane.

Figure 4.- Continued.



(c) Boeing 377 airplane.

Figure 4.- Continued.



(d) Douglas DC-6 airplane.

Figure 4.- Concluded.

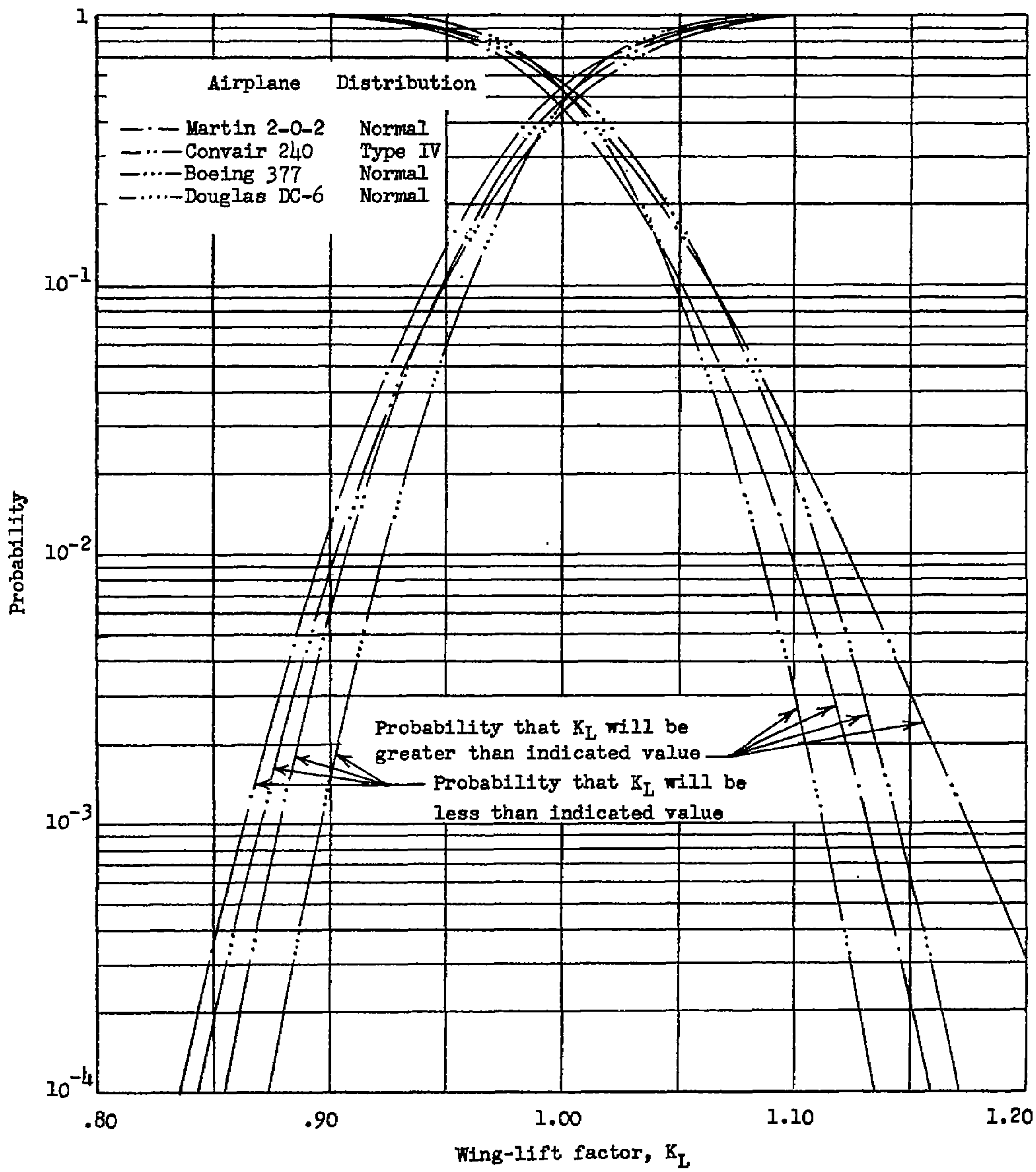


Figure 5.- Comparison of fitted probability curves for all samples of data.

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